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A CORRELATION THEORY
OF
COLOR PERCEPTION.

BY

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For Dr. Jno. S. Billings.
With best respects of the Author -

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lesions. The flexor surfaces are especially invaded. Upon the thighs and legs there is not a square inch that is not the seat of disease. The skin which is not occupied by distinct lesions is dark red and violaceous in color. The ankles are literally encircled with blebs and pustules, many of which have run together forming large, elongate, flaccid, partly bloody, dependent blebs. There is everywhere a tendency for the lesions to group, and while owing to their great multitude this is not striking in all regions, it is nevertheless very manifest in certain localities, as on the buttocks and thighs. The groups are for the most part small, consisting of from three to five lesions situated within a radius of an inch. In other places a dozen or more lesions occupy an area the size of the palm of the hand.

A peculiarity of the lesions is their disposition to coalesce. Inclining to manifest themselves in ill-defined clusters of two, three or more, as they increase in size they run together, forming larger lesions. Around the immediate circumference of these lesions, whether vesicular or pustular, smaller, flat pustules or vesicles, the size of pin-heads, are in many instances present. When ruptured the lesions crust over with flat, light, yellowish crusts. Removing these, superficially excoriated, moist, reddish surfaces, having sharply defined irregular vesicular or pustular borders are exposed to view. Everywhere about the older lesions there is noted a disposition on the part of the process to extend itself in a creeping manner while healing in the centre. Itching is present, and is very distressing.

Dec. 19. A month has elapsed since the last note. During this period four distinct attacks or crops of eruption have manifested themselves. The lesions in the first three attacks were of the same character as those in the outbreak of November 22d, just described at length, namely, vesicles, blebs and pustules, with but little inclination to intermediate forms, while in the present eruption *vesico-pustules* predominate. The last two attacks have been milder, with smaller lesions, but accompanied with more itching. The general course of the disease, the disposition of the lesions to cluster, and the regions invaded, have been the same as on previous occasions. At present the eruption is characterized by many small, and some large, variously shaped, *vesicles*, *vesico-pustules* and *pustules*, occurring in patches or scattered over the surface, in all stages of evolution, together with numerous excoriations, ruptured or torn lesions, crusts and scales seated upon a dark-red, violaceous, mottled, pigmented skin, the remains of former attacks. The patient is able to be about the house ; his general health is good. He has used lately alkaline tarry lotions. Arsenious acid, in doses of one-fortieth of a grain, has also been taken for the last three weeks ; also quinia, and a general tonic treatment.

In December, 1882 (four years after the last note), I received a note from the patient, stating "I am still troubled with the disease, and it has not failed to put in an appearance at certain periods since you saw me in 1878, although the blisters and pustules have gradually become less, both in number and in size. At certain times since, within the year, I was so free of eruption that at one time I thought surely I was rid of my pest. I can always tell two or three days before the eruption will appear by the coming on of an itching sensation. During the past six months I have had two attacks."

The history of this case, including the cause of the disease—a violent shock to the nervous system, is both interesting and instructive. The

bullous variety predominated, and when I first saw him, it was highly developed; subsequently, however (as in almost every case that I have encountered), other lesions, especially pustules, manifested themselves. The constitutional symptoms accompanying one exacerbation were marked.

ARTICLE VIII.

A CORRELATION THEORY OF COLOR-PERCEPTION.[1] By CHARLES A. OLIVER, A.M., M.D., one of the Ophthalmic and Aural Surgeons to St. Mary's Hospital, Philadelphia.

FOR some time past the author's attention has been directed towards the many conflicting and opposing theories of color-perception, some so filled with falsities and absurdities as to render them ridiculous, and others so veiled with useless perplexities as to maim and alter their intended significance. Whilst he is fully cognizant of the fact that he is but adding to the already overfilled list, he does not hope for indulgence if he be in error, nor does he apologize for anything that he may say. Individual firm convictions are presented in the knowledge that the only way for theory to become a law, is, that each shall contribute his mite of truth even though it be buried in a mass of rubbish. Taking for granted that the Huygenian or undulatory hypothesis of the imponderables is accepted, and that a difference in the number of vibrations makes a change in natural result, it must be self-evident that there can be given three positive assertions. First. That, as these actions are perceived, there must be organs able to appreciate them. Second. That each series of organs must have an apparatus able to respond to the quality of its perceived impression. Third. That as all natural imponderable stimuli are the resultants of a mere difference in the number of vibrations of one and the same ether, the organs for the receipt of the different varieties must be but analogues and modifications of each other.

Starting with the idea that each sensory organ is so adapted as to be able to receive its variety of impression, the assertion that there is a correlation in structure and action is arrived at.[2] This cannot be denied. Take the lowest sensation of animation, touch, and endeavor to compare it with the highest, sight. The tactile sense is seen in simplest protoplasmic mass, and it alone enables this primary form of living mechanism to exist. There has been given a quality to receive one of the simplest

[1] This theory was brought forward in a preliminary note published in the *Philadelphia Medical Times* for June 28, 1884. The present writing is the discussion of the subject *in extenso*.

[2] It is not necessary to discuss the first two assertions.

impressions of natural force, an actual contact with a resultant action. What is the visual sense in man, the highest creation, but a complex mass of simple elements, an engine capable of receiving many more impressions from the imponderables. What is vision but the result of an exalted character of contact[1] upon a physical difference so arranged as to be adjusted to the receipt of undulations equivalent to those of light! The physical tactile apparatus does not differ in any way from the physical color apparatus except in its form; the latter a more highly constructed variety of the former, each being adapted for its kind of stimulus. Of course every grade of animal life has its percentage of sensory power dependent upon the special development of the individual. The rate of increase being not only in the number of senses, but also in the evolution of an individual form. This is well exemplified by the sharp sight of some birds, the quickness of hearing, and the keeness of smell of some animals.

There cannot be any doubt of the fact that the special sensory portion of the organ of sight is intended wholly and solely for the determination of color. The thought that the sense of light constitutes the only visual factor of many of the lower grades of animal life, and that it must have been the primary form in the evolution of the now existent human visual sense, is, strictly speaking, incorrect. Natural colors are the exponents of a series of undulations of waves of light existing between two determinate ratios. Colorless light is the complete synthesis of such color vibrations. The more numerous the color combinations, the purer the light; the purer the light, the less colored it is; the less colored, the less visible. Pure light is invisible. Light to be seen must be colored, it must be impure. Consequently visual perception is of color and not of light, of which color there may be thousands of intensities of a single character of vibration from a dull reflection of a given natural red to the most intense reflection of the same natural red. All visual apparatuses, from the very simplest to the most complex, receive impressions of varying intensities of color. The simplest form of visual apparatus has probably but a few differentiations of impure light under its command. Thus in the epidermal eye spots of the most rudimentary types of animal existence, where resident nerve energies have been lifted from the sensation of varieties of heat vibrations into varieties of light vibrations, the impressions are limited to a few of the varying intensities of impure, colored solar beams. As the scale of life force is ascended, the numbers of received impressions increase, dependent not only upon acquired powers during the life of the animal, but upon the direct result of hereditary transmission of more highly developed physical structures capable of finer and more complex action. This continues in an interchangeable and

[1] The so-called "indirect."

irregular ascent until the acme is probably reached in some of the carnivorous types of tropical birds.

When the human visual apparatus is first placed in the world, and is exposed to color waves, it has nerve structures and material, which although never having seen the component colors of impure light, are physically fitted to respond to many of its vibrations, just as the leg, though never having acted, has its definite parts, such as the supporting bones, the propelling muscles, the governing nerves, and the supplying vessels, each in readiness for immediate action. The first moment that a beam of colored light is focused upon a sentient point of an infant's organ of sight, there is a transformation of the impinged natural stimulus into an equivalent nerve-energy which is transmitted to a cell, or plants a new cell in that infant's cerebral cortex, thus giving the receiving, transmitting, and recording cells each a new quality. A second impression is similarly received, a third, and a fourth, each stamping the working machinery with its representative mark. Repetition upon repetition of this occurs in all of the available responsive nerve materials, each single cell adding its mite, each mite strengthening and giving greater power to the organism, and each organism capable of perceiving as many colors as it holds under its jurisdiction. Assuming that complete external synthesis of natural color results in colorless light, and that incomplete combination in impure or colored light (the impure light being divided into invisible and visible), it must be concluded that the value of the total nerve force belonging to the various parts of one sensory filament is equal to a quotient represented by the sum total of all of its individual sensations if they had been extraneously combined to form some multiple color. From the theorems of natural color which follow, it will be seen that this quotient of value must be equal to some *impure* or *pure white*, but whilst this is undoubtedly so, yet in order to avoid confusion, the value of each filament's resident power and related perceptive nerve-force will be ordinarily designated as its normal power—merely using the specific terms when necessary. In these statements form, magnitude, distance, etc., are totally disregarded, because they are the results of combined action, muscular changes in and on the eye, changes in intensity of natural vibration, other sensory impressions both previously and simultaneously associated, memory, intelligence, etc. These taken in measure, or in all, in conjunction with the knowledge acquired by the sensory portion of the organ of sight, constitute what is called sight, the acme of visual result. To briefly illustrate, take the illusory effect of a picture representing an every-day scene. Here by the careful disposition of color and color only, the artist is enabled to seemingly designate form, magnitude, distance, etc., in fact all of the factors of sight. In this instance it must be acknowledged that the sensory portion of the organ of sight is excited by color vibrations alone, yet it is said that by this excitement the mind is brought to believe that

actual form, actual magnitude, and distance are in existence. How much more so for photographs where there are nothing but the so-called black-white intensities to act as stimuli! A moment's reflection will show how faulty the assertion. The mind through the aid of the senses associates previous knowledge with the present color perception, which gives rise to a pseudo-reality, and the picture appears real. Place the organ of sight in an unaccustomed situation where previous knowledge cannot be of any value. Allow it to gaze on a picture representing the same subject as before, though now seen vertically over the side of a balloon, and it will be found to be at an utter loss to correctly recognize anything but color; no definite ideas of form, magnitude, distance, etc., can be given. There is no previous knowledge, and sight is imperfect. How difficult are the attempts to estimate the length of time occupied during the falling of a small slip of white paper from a high tower to an uniform green sward! How often the calculation that the object has reached the ground is incorrect! The organ of sight is placed in a new and a novel situation, where it has no previous knowledge to associate with its present color perception, and as a consequence, sight is imperfect and the calculation false. Let it assume the same position, say several hundred times, and there will be found to be the most accurate idea of both the time of falling and the correct distance for that place. There is now previous knowledge to associate with the color perception, and sight for that situation becomes more nearly perfect. Crude and vague ideas of magnitude and distance are always given by the inexperienced to lone vessels on open seas or solitary mountains in deserts. In each case the eye sees as much and as well as it ever did, yet sight is imperfect, there being nothing for accurate comparison either in the past or in the present. The sensory portion of the organ is alone properly answered, and color perception is the only correct result.[1]

In telegraphy it is not necessary to possess an uncorrelative difference in the form of apparatus to be acted upon by an artificial division of a certain alphabet. As the resultants are only modifications of each other, they necessitate but corresponding changes in the working machinery. If there is a wish to attempt a higher grade of a similar stimulus, the apparatus is so modified as to allow the record to be correctly produced. The tactile apparatus is one form of telegraphic machinery destined to receive

[1] It may be of importance to note that there has been a distinction made in the terms "visual apparatus" and "organ of sight." This has been intentional. By "visual apparatus" is meant the peripheral and the central sensory nerve expansions, with the connecting sensory nerve-fibres, *i. e.*, the ocular or receiving retina, the cerebral or discharging retina, and the connecting sensory fibre (so named optic nerve); whereas, by "organ of sight" is designated the visual apparatus in combination with the entire ocular appendages—the muscles, the media, the tunics, etc. These distinctions apply as well to the other special senses.

its impressions, whilst the visual apparatus is another form of the same machinery intended for the receipt of the same character of impressions; each in itself a simple mechanism, not possessing differentiating power, but merely capable of response when properly acted upon. It would be foolish to assert that there may be special divisions of peripheral tactile nerves especially adapted for the three empirical sensory impressions—cold, warm, and hot; then to make an artificial gross division of caloric into several arbitrary parts, and say that the different varieties of results are the productions of differences in grade and amount of action upon each or all of these fibres (that the actions of natural fixed stimuli cause additions and subtractions of action in unknown degrees upon organisms of elective power). Yet here is Young's theory applied to the sense of touch. A theory slightly modified by such great minds as Maxwell and Helmholtz; accepted and held almost without question. Or how ridiculous to say that there are three tactile substances acted upon and producing three-paired primary tactile sensations, each peforming its duty in a sort of give-and-take manner, yet at an utter loss of reasoning to tell which gives and which takes. Here is the wonderfully ingenious theory of Hering considered from a tactile point of view. A theory framed and thrown to the world on account of the want of explanation of complementary color: a theory blindly followed by this great man's satellites and advocates.[1] The same line of criticism might be extended to the senses of smell and hearing, in first supposing several arbitrary odor names, or taking the now existent musical octave, and then endeavoring to form odor and sound theories to explain why these gross recognized differences in natural stimuli are smelt and heard.[2]

Why take the trouble to give a series of organic elements a coarse unnatural division of fibre, in an effort to harmonize them with an arbitrary and unscientific naming of visible color, when we have the difference of

[1] As these two theories are the best known amongst those that have been advanced since the remotest antiquity, the analogy has been limited to them.

[2] In the arrangement of this argument it might have been better to have compared these theories with similar imaginative theorems for musical sensation and perception, because not only of the close relationship existing between the two senses employed, but of the author's belief that the special sentient parts of the organ of hearing are intended for the reception and transmission of nerve energies equivalent to sensations of sound vibration alone, and that our ideas of distance of sound, direction of sound, character of sound, etc. etc., are but the results of combined perceptions and conceptions. Nevertheless, he has preferred the use of the sense of touch not only by reason of its wide remove in point of evolution from that of sight, but that he thinks the correlation can be traced here just as well. He also maintains that the peripheral parts of the tactile apparatus are destined for sensations of degrees in temperature only, which are transmitted as nerve-energies of specific and relative value to be perceived by the central organs. Ideas of solidity, weight, etc. etc., are but the results of previously gained knowledge and associated impressions from the other senses, combined with the so-called "muscular sense," which is nothing more nor less than an exact counterpart of the governing muscles of the organs of sight and hearing.

result dependent upon a difference in cause acting upon an ever-ready material? A difference in the character of natural impression affecting one and the same organic element to a greater or less degree, producing an exact and equivalent answer. For instance, suppose that a quantity of optic-nerve points in the human retina should be exposed to a beam of light of undulations, say, equal to five hundred trillions per second, the average response to the sensation thus produced upon healthy tissue would be what is known as "red." Each impinged point would excite a sensation equal to a specific energy equivalent to red. Again, suppose these same points were exposed to another beam of light of, say, six hundred trillions of undulations to the second, they would cause a sensation which would produce a specific energy giving the response of "green." Or let a beam of light, say of seven hundred and thirty-three trillions of vibrations to the second, be thrown upon the same sentient points, there would be "violet" given as the answer. Each and every optic-nerve fibre tip has a receiving power equal to its individual strength. Each and every healthy optic-nerve filament transmits to the color centre for recognition nerve energies equal to as many special sensations as its peripheral tip is capable of receiving. The innumerable quantities of nerve filaments placed side by side on a sheet or membrane serves to give greater field, and to allow many colors to be seen at one and the same time, thus making our every-day and momentary pictures. Therefore, in the author's opinion, the most rational theory is, that color-perception takes place through each and every optic-nerve filament. It consists in the passive separation of a specifie nerve energy equal to the exposed natural color, from a supposed "energy-equivalent" resident in the peripheral nerve tip, by an active chemico-vital process of the impinging natural color vibration upon the sensitized nerve terminal. The separated nerve energy is transmitted to the central terminus of the filament in the cerebral retina, where it is fully evolved into such a condition as to be transferred into an automatic form of perception by an action upon some unknown contiguous perceptive nerve elements: this constitutes the consummation of the nerve energy force into the lowest (and evanescent) form of recognizable color-perception. Finally, it is carried through similar posts and stations, though now of a higher value, as it was whilst pursuing its course inwards as a sensation, until at last it is completely recognized as intelligent color-perception in the higher color centres; these higher color cells being permanent in type, and forming parts and parcels of the higher perceptive cerebral centres. The first moment that the primary portion of this action (*i. e.*, the separation) has taken place, there has been left in the peripheral tip of the primarily impinged sensory filament a nerve-energy material equal to the difference between that individual nerve's "energy-equivalent" and the transmitted nerve stimulus. The healthy peripheral nerve tip returns to its "energy-equivalent," or normal nerve power, the mo-

ment the specific energy separated by the received natural vibration has been forwarded for transmission and recognition; whilst the transmitting filament and excited cerebral expansion regain their normal condition the moment the energy has passed them. After the consummation of such an action, the filament is again ready for any other natural color-vibration. The whole secret of the theory rests in the fact, that all natural color stimuli cause definite losses of nerve-energy material, whilst rest of the nerve produces restitution of nerve-energy substance.[1] To see red, the nerve is first supposed to be charged to its normal physiological condition by its inherent vitality and sensitizing material. Vibrations of five hundred trillions per second—a natural red color—are allowed to be thrown upon this sensitized tip. To see the color, the peripheral negative (an unused energy equal to the commencing sensation of a green) must be allowed to rest, by the separation of a quantity of nerve-force equal to a supposed red-energy from the "energy-equivalent," through the excitation of the impinging ray. This separated specific energy is transmitted to the lower color centre, where, although perceived, it is still more fully formed into a condition fit to be put upon record by certain higher perceptive elements, thus constituting the highest or intelligent perception of red. The moment that the red energy has left the nerve-tip, the terminal is again charged to its energy-equivalent, and is ready to receive any other color-vibration that may be cast upon its surface. The same tip is able to receive as many impressions of natural color as it holds similar sensations under its jurisdiction. Each and every natural color causes the separation of a specific energy equal to itself, which is properly transmitted and correctly perceived, if the conducting and central nerve structures be normal and intact.

It will be noticed that it is presumed that the sensation must begin in the peripheral termination of the visual apparatus (the ocular retina), because it is here that the primary change of an external natural force into an equivalent nerve-energy takes place, *i. e.*, the conversion of a natural impression into the first form of a sensation. This primary form of sensation is conducted inwardly by the so-termed "optic-nerve" (truly speaking, the intermediate connecting link of the optic-nerve), and spread as more thoroughly adapted and as a finished sensation, upon the intracranial retina, in such a form as to be readily converted into an equivalent perception by the aid of some unknown process of mentality. The sensation is first formed peripherally by the impinging natural impression upon an individual nerve tip; it is conveyed inwardly as such, by an intermediate

[1] This is the usual and normal order of progression in the evolution of a recognized color-perception from a natural color-stimulus; although, as will be explained, forces can originate in other ways, which may act upon any part of the visual apparatus or its related perceptive tracts and cells, and thus give rise to visible results.

connecting optic-nerve fibre, and at last is evolved upon a definite portion of the intracranial sheet or membrane as the same sensation, though now completely finished for conversion into a perception of an equivalent value: in other words, an impression of natural force upon a special sense apparatus, causes a peripheral change of that natural force into a nerve-energy (the primary form of the sensation), which is forwarded to a position and in such a manner that it is converted into a perception in certain definitive perceptive structures. This reasoning is dissimilar in measure from that which would be employed in the usual significations of the terms "sensation," "perception," and "impression," although in no way does it allow the visual apparatus to act as a differentiating body. In these remarks, the following distinctions between the terms "impression," "sensation," and "perception," have been ventured, which differ somewhat from those found in the ordinary books bearing upon the subject.[1]

1. An impression. The impinging of an extraneous natural force upon the peripheral termination of any sensory apparatus. The action of an outer world and a receiving material.

2. A sensation. The action of a sensory nerve. This in all instances commences peripherally, where a natural impression is converted into a nerve-energy of a relatively equal power; which energy is conveyed to a position and evolved into a condition by the transmitting and central structures of the apparatus, so as to allow a recognition by contiguous perceptive elements. The work of a receiving, conducting, and discharging material.

3. A perception. The recognition of a properly evolved sensation by an act of mentality through the excitation of definite perceptive structures in the cerebral cortex connected in some way with the central terminals of a sensory apparatus. The action of an inner world and a discharging material.

There cannot be any doubt but that the mind must act in color perception, or there would not be any visible world. To perceive color, the mentality must take cognizance of the action of an impinging color-sensation which has been ever altering and becoming higher and higher in its physical and physiological growths, from the time it was first formed from a peripheral impression of natural color-stimulus. If it be agreed that the laws of an act of color perception are similar to those of color-sensation, although the character of the labor of the former is of a higher order, it must be conceded that physical posts and stations intended for the evolution of the material qualities of the perceptive agency must exist. This implies that as color-perception has its regular development and growth, it must necessarily have a scale of efficiency or ratios of percep-

[1] In these definitions, abnormal and pathological stimuli are excluded.

tive powers. Endeavors to accurately place or express these powers, or even to give analyses of their various strengths, are futile as long as the union between mind and body remains a locked secret. It may be assumed, however, that there is much difference between what may be termed intelligent color-perception and automatic color-perception; and at this point, at this gross dissimilarity, the human mind with its present knowledge is compelled to stop. Automatic color-perception (by some termed color-sensation) is the primitive form of the perception, where although the color is recognized, yet the mentality is of such a low order that the perceptive color cells which have been primarily impinged —perceptive cells of evanescent power—would quickly lose their new quality, and the color-perception be forever lost, if they had not the power of transmitting it to the higher color-cells in the centres where intelligence, etc., the creations of the higher mentality, are brought into play, and which place it, as it were, upon record, so that it may be used in future requirements. In this higher situation the perception is stamped, the internal consummation of the external force takes place; here it is that the higher color-cell is either deposited or augmented so as to be brought into action as often as a proper stimulus attacks it; and it is at this place that these very cells live and play their roles, growing fat and healthy from use, shrivelling and dying from inactivity. What may be the situation of these higher cells of permanent powers, and how they live, must remain unanswered; for although physiological experiment and pathology have taught the probability of position of the lower forms, they have thus far failed to reveal the phenomena of individual and separate existence. No matter whether a force be of external or internal origin, if it either acts upon these higher-formed cells or makes a new corpuscle, it will cause intelligent color-perception (the so-called "perception"), because the newly formed higher cell or the increased material is in a proper condition and a correct situation to act in its turn upon the whole force of contiguous mentality. As the greater part of this mentality has been derived from the accrued results of the other sensory organs as well as from the visual apparatus, there may also arise an action of all of the other responsive cells, which response will cause an act called *sight*. So it is with the other sensory organs and channels from the outer to the inner world. Audition, olfaction, gustation, and taction, each may have added to its individual capability such mental factors as will produce hearing, smelling, taste, and touch. The manifold combinations of these final results with each other as well as with the processes of the deeper though derivative mental forces—such as emotion, volition, intelligence—constitute the *ultimata* of mental activity. The results of hypnotism, somnambulism, or in fact any of the so-called disturbances of the ganglion cells of the cerebral cortex, conclusively show this distinction. All this bears out

the saying of Epicharmus, the old Greek poet: "'Tis mind alone that sees and hears; all things besides are deaf and blind."[1]

The questions now arise: What is strictly meant by the expression "energy-equivalent"? Why is it supposed to reside in the peripheral termination of each optic-nerve filament? What is its value? What is understood by the term "specific energy"? Where is its residence? Why were these nerve-energies chosen? What is meant by normal condition? The combined answers to this series of questions may be given in the following paragraphs. At the peripheral tip of every optic nerve filament, there must be two separate and distinct actions in the receipt and the conversion of a natural color-stimulus into an equivalent nerve-energy. First, a separation of a nerve-force physiologically equal to the amount of the natural stimulus of the impinging extraneous vibration, from the normal conditions of the "energy-equivalent" resident in the tip of the impressed nerve; and secondly, a return to the now lowered remaining nerve-energy material, of an energy matter equal to the separated amount of force, the moment the natural color-stimulus is withdrawn, thus changing the remaining energy to the normal energy-equivalent. What this force is, and how it is formed, separated, propagated, and reformed are all difficult problems to attempt to answer. Many thoughts, such as chemical decomposition, molecular vibration or oscillation, direct transmission of vital force, suggest themselves, but no one can positively say which one of these, or whether all, or even some other yet unknown force, can be considered as the true sensory actor, until discriminating instruments can be brought to play upon the living and acting organism. It is probably of a purely chemico-vital character, placed in such a situation as to permit stimulation of natural color upon it. It is not possible to give it any determinate and fixed ratio of value, because this must be dependent upon the vitality and strength of each optic nerve filament. Each tip is born into the world and exposed to light with a definite amount of developed physical material just as any hereditary or congenital feature, a foot, a hand, etc., and it, through the same amount of physiological action as another optic-nerve tip not so well developed, gives greater and finer results than its fellow; thus stamping that individual optic-nerve tip in its peculiar power of action. Again, if two tips have primarily the same amount and the same grade of physical structure, their life histories may be such, in reference to situation, position, exercise, etc., that they will each develop and

[1] The fact that the reader dissents from this division of action in vision, and desires rather to believe in the terms "impression," "sensation," and "perception" as generally received, does not affect the correctness of the theory at all. The author gives but his personal beliefs as to the use of the expressions, which might with equal propriety be abolished by any disbeliever, and yet the foundation of the fabric remain secure and untouched.

have far different sensory material and power. Roughly speaking, the quotient of value of each individual "energy-equivalent" is equal to the subjective sensation (with consequent perception) of as pure and as colorless an energy as its individual past objective sensations would make if they had been extraneously combined as separate color vibrations to form a natural impure beam of light (some impure white).

By the term "specific-energy" is meant a specific amount of sensory nerve force which has been primarily separated from an energy-equivalent resident in the peripheral terminus, by the action of an impression of natural color. This separated energy always bears a definite relation to the amount of natural color-vibration. After separation, it is evolved into a higher grade of action during its passage along the transmitting apparatus, until at last, it is spread as an almost fully developed force in a relatively similar position upon a cerebral membrane ready to be still further charged to a sufficient vitality to act and to be acted upon by some mental equivalent.

The reason of the choice of these two forms of this special sensory force must be palpable after the above explanations; they serving as full an answer to the proposed questions as any other that might be added. Besides, such a theoretical designation of nerve-energy admits of much more convenient practical testimony in its behalf, than any other form of speculative argument bearing upon the subject.

The last question, "What is meant by 'normal condition'?" is almost self-answerable. It was chosen, however, to serve as an expression of difference to the specific term "energy-equivalent," as expressing a mere physiological rest, just as would be found in the normal condition of any other acting body. In this distinction, it must be understood that there may be a primary excitation of this material by some internal force, with a resultant corresponding physiological action, just as freely as if the "energy-equivalent" had been stimulated.

This theory has the following theorems of natural color for its basis:—[1]

1. The general convenient adoption of the seven so-called primary colors, or of the solar spectrum being made of three graduated overlaying spectra must be discarded, as these are nothing more nor less than crude visual and mental distinctions made through the want of perfect physical condition and physiological ability.

2. A difference in kind of undulation makes a change in natural color, and every such change must be called a "primary natural color" or a "pure natural color"; on account of its being the representative of a specific character of vibrations totally different and distinct from any other primary natural color. There are as many separate primaries or

[1] By "natural color" is meant every species of independent and combined light vibration (except total synthesis), in contradistinction to "visible" or "sensory color," which is a mere visual and mental exponent of such wave lengths.

pure colors as there are difference in undulations between the extremes of color-vibration.

3. A "secondary natural color" or a "tone" is the result of the addition of any two pure natural colors or primaries.

4. A "multiple natural color" is the result of the addition of two or more tones, or of more than two pure natural colors.

5. Colorless light is the compound of all natural color, the origin of all separated natural color vibrations. The purest example may be represented by the synthesis of a resultant spectrum produced from the combination of all of the spectra of all of the natural elements in all possible conditions. To human knowledge, there is no single natural body which contain all of the natural elements; consequently to human knowledge, there is no individual body that can give rise to pure colorless light. Every light-giving source, such as a sun, electricity, chemical and animal change, gives a definite color-spectrum equal to its constituent elements. Hence there must be two varieties of colorless light, pure and impure.[1]

6. By an inherent synthetical power, every light-giving source gathers and collects all of its individual elemental spectra into a compound natural energy. Portions of this energy are propagated into all free space as undulations equivalent to those of invisibly impure and visibly impure colorless light. These vibrations upon being received by a natural object, are either fully absorbed, totally reflected, or broken into two portions, the absorbed and the reflected; this being dependent upon the nature of the impinging beam and the character of the impinged object; the reflected portion gives the natural color to the object. The amount of the separating action is dependent upon the relation existing between the active power of the impinging beam and the passive resistance of the body. A slightly impure beam is able by its relative action upon innumerable bodies to separate itself into innumerable colors, whereas a decidedly impure beam separates only the varying tints and shades of its own kind.[2]

7. Pure complementary color. Every natural color has its complementary, to which, if it be combined in certain ways by a natural object, gives either pure white or pure black.

Pure white is caused by the simultaneous reflection in a definite direction of any two pure complementary colors, or of any even multiples of pure complementary colors, from an impinged natural object. Hence,

[1] The impure white light of the earth's sun is an impure colorless beam, the representative of the solar constituents.

[2] As a matter of course, the visual apparatus cannot see invisibly impure light. Such light falls upon the sentient parts of the retina as well as upon any other natural body which absorbs and reflects. The amount of reflection gives to these sentient tips their natural color. They are fitted to respond only to energies equal to impinging reflected rays. (All transmitted rays to be seen, must have surfaces or points of reflection.)

pure white is a positive or a visible tone, of which there may be innumerable varieties.

Pure black is caused by the simultaneous absorption of any two pure complementary colors or of any even multiple of two pure complementary colors, by the passive action of an impinged natural object. Hence, pure black may be considered as a negative or an invisible tone, of which there may be innumerable varieties. It is not a color, and has darkness for its equivalent.

8. Impure complementary color. Every natural color, primary, secondary, or multiple, has innumerable impure complementaries. If there should be a combination in certain ways of any one or more of these natural colors with one or more of its impure complements, there will result an impure white or an impure black—a tint or a shade.

A tint is the simultaneous reflection in the same direction of two or more impure complementary colors, from an impinged natural object. The preponderant wave serves as a basis for the color.

A shade in the simultaneous absorption of two or more impure complementary colors by the passive action of an impinged natural object.

9. Darkness: two conditions.

a. Produced by the interference of two or more series of undulations. The rising phase of the one exactly corresponds in position and time with the sinking phase of the other; thus they neutralize each other, and give rise to the loss of positive color. It may be designated as positive undulations so interfering as to give negative results. Of these, there may be many varieties.

b. True absence of light undulation. Here there are no stimuli productive of color ether-waves, hence no results, either positive or negative. This condition is directly opposed to pure colorless light.

PHYSIOLOGICAL RESEARCH.—As before intimated, in the human system, every special sense apparatus has three separate parts. First, a peripheral expansion intended for the reception of natural vibration equal to its powers of primary sensation. Second, a series of telegraphic communications, inclosed and insulated, separated and adapted for the transmission and the partial evolution of equivalent nerve energies. Third, a central expansion, upon which is spread the received result, ready to be fully evolved and transformed into a perception by a contiguous nerve material endowed with the power of mentality. The visual apparatus is but one of these forms; a sensory nerve development adapted for impressions of color; and from this standpoint it must be studied. Naturally, inquiry would be made for methods of determining the comparative relations existing between the exciting stimuli and the degree of sensory power of the apparatus. Mathematically, this has been found totally inadequate; so that at present, not possessing any absolute data for ratios

of equivalence between the strength of the impinging beam and the appreciation or value of sensation of the receiving fibre, except those based upon physiological investigations and clinical experience, these have been deemed sufficient for a time at least, to endeavor a proper enunciation of the theory. The question of the value of theorizing as to the *modus operandi* falls to the ground, the moment that it is unbiasedly considered that having but one premise fixed to the equation no conclusion can be arrived at. Theoretically, the beam of light of the least number of vibrations should be that of the easiest recognition, but then the questions arise— Does not such a beam cause less sensory disturbance? Does it not excite the filament the least? Would not a stronger natural impression give a correspondingly stronger nerve-energy? What relation may the intensity of the natural color vibrations have upon the ease of impression? All of these are serious questions, which must remain unanswered until ingenious instruments of such precision are made, that can with unerring accuracy and the utmost delicacy give the actual rates of known impression and passage of equivalent nerve-energies. All, therefore, that can be reasonably presumed, is, that there must be a normal condition to which the nerve filament must return after each individual impression has been conveyed. This has been brought forward more at length in the previous part of the paper, and upon it the whole superstructure rests. In this section of the subject endeavors shall be made to study and give some physiological explanations for its choice, and add a few reasons why its probability may be entitled to belief. After much deliberation, it has seemed best to consider the different results under the following heads:—

First. Color-perception as produced by color-sensation commenced in the macular region of the ocular retina.

Second. Color-perception as caused by color-sensation primarily formed in the circummacular region of the ocular retina.

Third. Color-perception directly resulting from provoked remaining nerve-energies. Subjective after-color (so-called complementary color).

Fourth. Color-perception caused by the action of internal stimuli upon nerve-energies which have not been lowered by any preceding act. Subjective color.

First. Color-perception as produced by color-sensation commenced in the macular region of the ocular retina. From time to time experiments have been instituted in various ways to determine the qualitative and quantitative limits of normal color-perception derived from color-sensation primarily made at the macula lutea. Those for the determination of the latter have been the more numerous, and these have been limited to a few of the more important and valuable color differences. As might be expected from theory, experimentation has revealed that although all individual macular regions have definite relative powers with each other, yet no two possess exactly the same amount of color-sensation; thus con-

clusively showing that each has a different amount of nerve-tissue and nerve-energy. This can be understood when it is considered that the great varieties of physical differences in similar normal organs, must necessarily give proportionate differences in normal physiological action. Consequently, here it has involved the use of standards for a proper solution of the average strength of color-vibration upon those optic-nerve filaments which are deemed by all physiologists to be of the highest physical organization—the filaments resident in the yellow-spot. Briefly, the order of the standards for five of the most important colors have been red, yellow, blue, green, and violet, showing that a natural red vibration excites an optic-nerve filament the quickest, followed by the others in the order given above.[1] At present it will not be necessary to offer any explanation why these colors follow each other with such regularity. Suffice it to say, that, as before intimated, it can never be hoped to gain a proper solution to the problem until vital energies can be reduced to mathematical certainties, although an adequate answer, based upon the combined results of physiological research and pathological study, will be reserved for the concluding paper.

Second. Color-perception as caused by color-sensation primarily formed in the circummacular region of the ocular retina. Really no sharp line can be drawn between these two headings, as one is a gradual lessening of the other; but as the experiments have been dealing, in the investigation pursued in this connection, with the furthermost limits of the generally used portion of the ocular retina, in contradistinction to those of direct use, it has seemed better to make the classification so as to have a comparison between the weakest and the strongest filaments of the nerve. Two plans were adopted: One, to consist in the study of the ordinary visual fields, and the other in investigations as to the possible recognition

[1] This has been partially determined, and will, probably, be continued by the writer in experiments differing somewhat in detail of method from any others with which he is acquainted. An emmetropic eye with good color vision is placed at the extremity of a blackened tube six metres in length by ninety millimetres square. No light is permitted to enter the eye, except from the opposite end of the tube, and this through a graduated double shutter, practically similar in all respects to the author's color-sense measure (description in *Archives of Ophthalmology*, vol. x. No. 4, p. 438), with the exception that transmitted light is used instead of reflected, as in his previous experiments; this being accomplished by the substitution of thin, transparent plates of colored glass, or gelatine, in the opening between the shutters, for the squares of colored paper previously employed. The movable slides in the newly adapted color-sense measure are slowly separated, and the area of exposed color registered the moment it is properly designated. This plan is pursued in such a manner that there can be nothing but a certain amount and kind of color-stimulus to affect any desired region of optic-nerve filaments. To complete the experiments, and to make them of fixed value, there should be some mechanical device constructed by which the shortest time necessary for the perception of the color could be accurately determined and registered. Valuable results might also be obtained by diminishing the illumination as in the experiments of Bull.

of all of the colors (equal to the power of the individual macula lutea region under observation), in the periphery, by increase in illumination or in quantity of color exposed.[1] As far as gone, all of these showed the following results:—

[1] It has not been thought necessary to accurately describe the proposed methods, but merely to state the character of experiment with a description of the instruments in use. For the first series, perimetric observations are made with areas of reflected color upon both black and white surfaces, as well as examinations of the same character, by the employment of transmitted color-stimulus alone. This latter method is deemed worthy of full description, not that the device of instrument is the best, but that the plan in itself is probably the only proper way to obtain accuracy in the size and extent of the different visual fields. In a large darkened box with a circular opening cut into one of its sides, there is placed a normal emmetropic eye, at about thirty centimetres distance from a small roughened wooden button fastened against the upper end of a narrow flat glass rod so arranged that both the eye in the box and the button in the centre of the open area will be situated on the level with each other. This window is of much greater size than any normal visual field. A piece of pasteboard several times larger than the opening in the box is held against the window. In the centre of this pasteboard screen there is a hole of one centimetre square, in which can be placed thin sheets of colored glass or gelatine. As many pieces of color may be used as desired. By sliding the large pasteboard card so that its central hole may be allowed to perform excursions in all directions from the periphery of the now covered window to its centre (which centre is made visible to the eye within the darkened chamber by the rubbing of the wooden button with a piece of stick phosphorus), the hole in the immense shutter is caused to act as a definitely sized area of movable transmitted color stimulus. The moment the color is recognized, as it is brought inwards, its distance from the luminous button is measured, so that when the circle is completed, the different distances can be registered upon small memorandum slips ruled to proportionate values of space. As many different color fields as desired can thus be taken, and small registers kept for future reference and accurate comparison. The objections as to the methods being crude, cumbersome, tiresome to the patient and surgeon, the difficulty of working the instrument, etc., might be easily overcome by the substitution of adaptations of better construction. In the studies pursued in this paper, all this would be but afterthoughts, as here it is but desired to get a working instrument of sufficient capability to give proper answers to the experiments. The advantage of the plan must be manifest in the fact that there is no other stimulus present except that of the desired color and a faintly luminous spot of just sufficient visibility to keep the optic nerve fibres of the macula lutea fixed in a position to preserve proper steadiness of the globe.

The second series of experiments, where it is designed to study the comparative strengths of the most peripheral and the central distribution of optic nerve fibres in the ocular retina, have been partially attained and will be probably accomplished by putting the eye in a darkened chamber. The macula lutea will be kept fixed upon a small, white, faintly-luminous object consisting of the passage of common daylight through a piece of uncolored translucent glass placed in a hole one millimetre square cut in one wall of the chamber. In a position corresponding with the most peripherally used parts of the retina (*i. e.*, the outer horizontal meridian of the visual field), thin, transparent plates of colored glass or gelatine of known values are to be placed in an opening ninety millimetres square cut in the wall of the chamber in which the central hole is pierced; this opening can be changed in position to correspond with each case. In this opening there is a movable slide of the same character as in the author's color-sense measure, by the working of which, any desired amount of color surface may be impinged upon by direct and indirect beams of sunlight of greater and

1. By the same amount of daylight, the superposition of a definitely sized area of unglazed reflected color upon a dead black surface, gives the largest visual field to white, followed by yellow, blue, red, and green in the order named.

2. By the same amount of daylight, the superposition of a definitely sized area of unglazed reflected color upon a white surface, gives the largest visual field to yellow, followed by blue, red, and green in the order named.[1]

3. Perimetric observations upon black backgrounds, show that with equal illumination, all reflected colors undergo definite changes during their passage across the fields towards macular fixation.

The following is the order for those experimented with: A definite area of white first gives a peripheral sensation of gray, which gradually passes to white. The same size of yellow impression, first appears as gray, then white, then lemon-colored, and at last yellow. Blue first appears as gray, and successively passes to white, bluish, and blue. Red first shows itself as gray, then white, followed by orange, salmon-color, and red. Green first appears as gray, then white (sometimes bluish), and then greenish, before it gets to its true color.

4. In perimetric observations with reflected color upon a white background, the same phases of color-change are undergone as in similar ex-

greater intensity, at last supplanted by gauged intensities of electric light. These beams are made to pass through a blackened tube six metres in length by ninety millimetres square, placed on the outside of the chamber; the extremity of the tube being fastened against the large eccentric opening containing the different colored plates. This contrivance enables us to expose to the peripheral portion of the observing retina, graduated intensities of chosen colors. Notes of the size of the color stimulus and of its intensity will be taken as soon as the color is properly called. A ready comparison between the qualities of the same color as perceived through the peripheral fibres of the ocular retina and through the macular fibres of the same ocular retina, will be made by putting a similarly colored piece of glass or gelatine as has been used in the large eccentric opening, in the place of the plain translucent glass used for macular fixation, and giving to it the same amount of illumination as has been used for the peripheral color. To estimate the proportionate physiological values of the most peripheral and the macular optic-nerve filaments, more and more surface of the eccentrically seen area will be exposed until the macular and the peripheral colors are determined to be as alike each other as can be gotten. (This plan is but a modification of that of Charpentier. Snellen, Landolt, and Aubert have experimented in other ways.) After the establishment of the visual results, valuable information as to the order of peripheral loss of colors could be easily gotten in a series of converse experiments by mathematical diminution of color intensity and area.

[1] As black is not a color, its relative situation was not placed in the list, although a similar area of it upon a larger surface of white was tried, which showed a projected position of the unimpinged optic-nerve filament into the visual field. This area of defect was made known far more peripherally than the places of primary receipt of any of the color vibrations, on account of its being inclosed in a space of recognized white stimulus.

periments upon a black background; every color tried, with the exception of white, first appears as an area of non-impression.[1]

5. When visual fields are produced in the same amount of daylight, by the use of transmitted color, the largest area is that of white, followed by yellow, blue, red, and green.

6. As far as investigations have gone, the following may be laid down as a rule. By increased light stimulus all of the different colors responded to by optic nerve filaments in an individual macular region can be recognized when exposed to the most peripherally used elements of the same retinal area.[2]

Third. Color-perception directly resulting from provoked remaining nerve energies. Subjective after color (so-called complementary color). The term complementary color has been avoided because it does not express the true condition of things; it only shows that there is a color which appears to be the complementary of another color previously seen. Therefore in consequence of a wish to give a precise designation for the character or kind of action as well as one for the state of existence of the working material, in the place of a term which is merely indicative of a recognizable symptom, the above expression has been substituted. Possibly it might have been advisable to have placed this part of the subject under the heading of the so-called color-blindness, because both conditions are nothing more nor less than true species of each other. As will be explained, the former is a momentary faulty answer, the resultant of imperfect physiological work, through normal physical incapability; whilst the latter is a permanent[3] faulty answer, the resultant of imperfect physiological work through abnormal physical incapability. On account of "complementary-color" being as universal as vision itself, it has assumed a similar physiological basis, and must be considered under

[1] This is readily explained. In this experiment we are dealing with a white background, which is the largest visual color-field. All the other color-fields are proportionately smaller; hence the boundary of the white field must be the peripheral limits of color-vision. A small white area is first seen as gray at the border of its white field, because at this point it necessarily must give its first weak sensation. The other color areas have a certain space of peripheral white color vision to travel over before they commence to be recognized; consequently, the superposition of one of these natural colors anywheres in this space, must necessarily take away the vision for white in the superimposed position, and yet fail to give any impression whatever. Hence as a consequence, there is an area of subjective darkness—an area of unrecognized color-stimulus.

[2] The author's experiments in this direction have not been completed. They have been limited to the mere question of recognition of the five color-differences—white, yellow, blue, red, and green. He has partially determined that the comparative values of the experimented colors are in the order as given above.

[3] By "permanent" is meant a time corresponding to the continuance of the causative pathological structural change.

the physiological laws of the visual apparatus. Hence it has been placed here. In order to facilitate the studies in this branch, the results and reasonings of previous investigators have been combined with some additional experiments and analyses, and from these, certain suppositions as to causation have been framed. As said in the other headings, it does not seem necessary to give each individual example of research; for, besides being burdensome, it would but add much unnecessary detail, where resultant averages could be readily formulated and briefly given. It must be granted that all such changes are necessarily of a purely subjective type—a momentary alteration of physical structure causing a consequent relatively faulty answer. The exciting stimulus may be either peripheral or central—external or internal; it does not matter which, as long as there is a passing fault in the machinery, there will be a corresponding fault in the product. This gives the first grand division of "subjective after-color;" first, those produced from the external world or natural light stimulus; and second, those from some internal stimulus, either in the visual apparatus, or in the cerebrum beyond it. In a previous paragraph it has been more fully shown and explained that every sensory nerve has at its peripheral termination two separate and distinct actions in the receipt and the conversion of a natural color-stimulus into an equivalent nerve energy; first, a separation of an amount of nerve force equal to the amount of an impinging natural stimulus, from the normal condition of a resident nerve-energy; and second, a regain or a return of an equivalent amount of material to that nerve's "energy-equivalent," the moment the natural stimulus is taken away. This rule holds good for the entire length of the sensory filament as well as for the related perceptive elements in the cerebral masses. Should there by any means be another color-stimulus presented to the primarily impinged optic-nerve filament tip, before it has had time to regain its normal condition, the new color-stimulus will be reduced in its equivalent action by as much as the primary color-stimulus has taken away, and the result in all cases will be a proportionate difference. In other words, there is a moment before the lowered sensory nerve can be made to properly obey its physiological law. Thus, suppose a red stimulus should be superimposed upon a white stimulus (*i. e.*, a red wafer upon a sheet of white paper), and that the red vibrations should be allowed to impinge upon an optic-nerve filament, the natural stimulus would separate a nerve-energy equal to itself from the "energy-equivalent" of the impinged optic-nerve filament, and continue to do so as long as the red stimulus is there. This is an act of continued separation. Again, suppose that this natural red color should be suddenly removed. By this act there would be a natural stimulus of white sent to the same nerve in which the "energy-equivalent" has been lowered to an energy of an amount equal to the difference between the nerve's normal power and the red energy. No time has been allowed for

the "energy-equivalent" to be properly re-formed. There would now be a dual action for the impinged nerve—a regain of the separated amount of the red energy, and a separation for the impression of the natural white stimulus. The result would be a difference between the white and the red, which is equal, in this case, to the commencing sensation of some green.[1]

The same thing occurs when the so-called complement is provoked upon some other color surface than white. By the sudden substitution of a new color-stimulus, the excited nerve is rendered momentarily abnormal for the amount of regain of the primarily seen stimulus. If this second color-stimulus be of greater value than the amount of nerve-energy left in the optic-nerve filament tip, the actual result will be an answer to a nerve action equal to the amount of energy left by the primary stimulus, which of a necessity will always be a complement of the primarily seen color. To explain: if a natural red stimulus be superimposed upon an orange ground, theoretically in this particular instance, there would be either one of two things, each dependent upon the separating power of the second color. First, a proper receipt of the natural orange color (in which case there would not be any complement at all, because both the primary and the secondary natural color-stimulus would be properly answered), provided that there be sufficient nerve-energy material left from the separating action of the primary red stimulus upon the energy-equivalent of the optic-nerve filament tip, to be separated for transmission and perception of the after natural orange stimulus. (Here the separating power of the second natural stimulus (orange) is considered to be low.) Second, a subjective after-color of some green upon the orange ground. The remaining energy would be stimulated to its utmost by a natural color of greater power than it is capable of receiving. As has been shown, the energy that is left is always equal to the subjective complement of the primarily seen color; and, as a consequence, this amount of energy is all that can be separated for evolution into a completed perception. (In this latter supposition, the separating power of the second natural stimulus (orange) is considered to be high.) This latter is what takes place when the so-called complement is produced.

The belief that black is the complement of white is obviously incorrect because it is based upon false premises. This refutation admits of ready

[1] A good example of a subjective after-color produced from a natural white light after prolonged exposure of the eye to a red stimulus, was once experienced by the writer. One dark night whilst he stood watching some men at work before the blast furnaces of a large rolling-mill, his attention was particularly attracted towards several huge pieces of iron heated to a cherry-red color, that were standing in a dark corner. He gazed at the blocks for some time, and upon turning to walk down an unlighted street, noticed that the light of a distant lamp appeared bright green, and continued so until he had nearly reached it. He then saw that the lamp was covered by a white shade.

explanation; for when a certain number of optic nerve filament tips have been exposed to a definitely sized square of natural white stimulus upon a larger area of neutral gray surface, there is an answering nerve material separated as a white energy as long as the tips are directed towards the natural stimulus. As this white natural stimulus has been derived from an ordinary impure natural colorless energy, it contains all of the complements of that natural energy, and *par consequence* must have impressed and separated all of the nerve material of the impinged tips. This separated white nerve energy is transmitted and evolved into a perception of white. Suppose this certain natural white stimulus be stopped, and another similarly sized and placed area of white stimulus be given to the impinged nerve-tips before a formative action could have taken place in the nerve energy material; all white sensation and perception would be at an end, because the second white natural stimulus would take away the nerve-energy material as fast as it would endeavor to re-form, and would not allow any of it to be separated for transmission and perception. This condition would last until the nerve-energy material could sufficiently regain itself for separation. Consequently there would be a space of true physiological darkness equal in size to the space occupied by the primarily perceived white color, which was produced from the first natural white stimulus: an area of "physiological nothing" made visible by surrounding color, just as a hole in a board is seen; this area being dependent upon the inability of the peripheral tips of a quantity of sensory nerves to properly receive a series of impressing natural waves. This can be proved by the following experiment: Make of unglazed paper a card containing three concentric rings, each ring of three centimetres width. Let the middle one be white, and the two outer ones black. Hang the contrivance directly in front of a nine centimetres wide ring of white paper, upon the gray wall of a badly-lighted room, in such a manner as to completely hide the white-ring card. Gaze attentively at the black and the white rings for at least fifteen seconds. (Preferably do this when tired and fatigued, as the result is much more prompt and vivid.) Whilst keeping the eye steadily fixed, have the outer card suddenly removed, which action will give the impinged optic nerve filament tips a white stimulus to respond to. Instead of a receipt of white there will subjectively appear three concentric rings, the outer ones being white, and the inner one *dark*. This experiment also explains the fact that the exposing of sensitive peripheral nerve-tips to a black surface does not cause a separation of sensory nerve force in the exposed terminals; thus conclusively showing that the popular idea of white being the complement of black, is nothing but a crude and false deduction based upon premises which confound a want of action with action—an error that has arisen through the belief that a black surface is an area of natural sensitizing material.

The superposition of a natural white stimulus upon any other natural color-stimulus than white, practically causes an area of momentary darkness, because the primary natural white stimulus has used all of the resident nerve force, and time has not been allowed for the formation of sufficient material to transform the second natural stimulus into an equivalent nerve-energy. This want of action prevents the second natural color from being perceived.

The series of passing subjective after-colors produced by excluding all natural light rays from the visual apparatus, after it has gazed for some time upon pieces of white paper on black surfaces, held in direct sunlight, seem to depend upon the fact that the primary extraneous white stimulus has been of such great intensity that even after it has been completely removed, it has left an irritant action in the exhausted peripheral tips, which of a necessity will separate for transmission and perception specific nerve-energies from the re-forming material as fast as the material is poured into the tips. The fact that the irritant action is ever decreasing, with a proportionate gain of the nerve-energy material in the tip, is the cause of the succession of subjective colors. For instance, a definite number of optic nerve-filament tips have been exposed for some seconds to a white stimulus of very great intensity. The extraneous stimulus is suddenly stopped. All of the nerve-energy material has been extracted from the exposed tips. A formative action immediately takes place, but this is met with an irritant in the shape of the remains of the intense white natural stimulus. A contest takes place between the formative action of the nerve-energy material and the irritant. The irritant separates the nerve material as fast as formed. The gradual loss of irritating action is evinced in the passing changes of perceived color. The victory is given to the nerve-energy material, because the material has had a source of constant renewal, whereas the irritant action has died from the want of fresh supply of natural stimulus. It may be that this result is indirectly augmented by a devitalizing action of the intense white stimulus upon the organic constituents of the tip itself, which physicial alteration prevents proper physiological working; the various color changes being dependent in some measure upon the character of the reparative action taking place in the recipient tissues. This supposition is borne out by the so-called blending effect of direct sunlight upon the human retina.

If, instead of excluding the visual apparatus from all natural light after it has gazed for some time upon the pieces of white paper on the black surfaces held in the bright sunlight, it should be immediately re-exposed to the same slips of white paper to which the first exposure was made, there will subjectively appear the same character of passing colors as were made subjectively visible in the preceding experiment, except that now they will progress in a *reverse* order. The reason for this can be readily

given. During the time that the reimpressed exhausted tip is gradually gaining sufficient nerve-energy to transmit the second natural white stimulus, there is a corresponding separating process continually taking place, dependent upon the great intensity of the *second* natural white stimulus. These separated amounts of nerve-energy are forwarded to the perceptive centres where they are recognized. This continues in a definite order of gain, until at last the second natural white stimulus is able to be properly received as an equivalent nerve-energy, which is transmitted and perceived as "white."

Both of these experiments first show the so-called "objective complement" of the primarily exposed natural color, followed by visible expressions of regain of nerve-energy material under different circumstances.

The subjective after-colors seen by an eye exposed to a feeble stimulus of natural color when its fellow is made to receive a strong stimulus of some other natural color, must necessarily be dependent upon a transformation of a "remaining energy" of one of the primarily used perceptive color-cells belonging to the strongly impressed visual apparatus, to an equivalently placed perceptive color-cell belonging to the weakly impressed visual apparatus; the primary weak excitation of the secondarily and internally impinged perceptive color-cell causing a primary separation of but a minimum amount of nerve-force material to be regenerated for recognition and projection of the internal stimulus. It is nothing but the action of the "remaining energy" of a lowered though highly excited perceptive color-cell belonging to one channel to the external world upon another similar and responsive perceptive color-cell with a "remaining energy," belonging to a like channel to the outer world. As the most probable cause for this character of response must have been dependent upon a connection of the perceptive cells belonging to the two sensory apparatuses, although, from the very nature of things, all normal human cerebral action must ordinarily be dual in its physicial nature and physiological action, yet it is the most reasonable to suppose that *at the time* of the double action of the visual apparatuses, the perceptive cells of each were physically and physiologically thrown into connection with each other. How this may have been done, whether by continuity of material tissue, chemico-vitally or by some unknown agent, it is impossible to say. That there is an organic or life connection at such times is known by the blending of the finite results; but even if continuity of molecule could be traced during such action, the fact of a new perceptive color-cell being attacked by a definite stimulus, which sets free a specific energy, does not destroy the weight of the argument that might be forwarded for not considering it a "subjective after-color" in the same light as the author, because the internally impinged cell has been lowered to a "remaining nerve-energy" by its weak primary action. Thus, in one of the interesting and ingenious

experiments by Gorham,[1] where a subjective green is made to appear to a visual apparatus which has been exposed to a weak natural white stimulus, whilst the opposite visual apparatus has been given a strong stimulus of natural red color, the answer cannot be arrived at in any other way. The fact of white being the weak primary separation in this experiment appears as a vulnerable point in the argument; but the force of this is controverted by the extreme weakness of the intensity of the action from the natural white color, in contradistinction to the great strength of the opposite internal stimulus, the question being one of a difference in intensity.

The same character of reasoning that has been offered in explanation of the preceding class of experiments may be adduced in favor of the so-called "simultaneous contrast colors," in showing that either the action of simultaneously powerful and feeble intensities of natural color stimuli or of a prolonged exposure of a strong and a weak natural color impression upon a series of contiguous peripheral nerve terminals of the same visual apparatus can readily provoke an internal irritant action in the strongly excited perceptive color-cell, which will, in its turn, cast the entire brunt of its remaining nerve-force upon its feebly excited neighbor, and thus rouse the now secondarily impinged cell into a corresponding action. This is found to be most likely the case, when it is remembered that these cells have probably through their simultaneous primary action been physically and physiologically thrown into connection with each other. It will not be necessary to give the many variations of this variety. The recital of two experiments will suffice for all. First, when a small square of weak red stimulus placed upon a large area of intense natural red appears greenish, the supposition as to causation belongs to the first rule—"simultaneously powerful and feeble intensities." An experiment illustrating the second rule, *i. e.*, prolonged exposure of a strong and a weak natural stimulus may be cited by having a small strip of dull-grayish paper placed in juxtaposition to a similarly sized strip of a bright-green paper, in which case, after some seconds' exposure, the border of the dull-gray strip next to the bright-green will have a reddish cast.[2]

The so-called "multiple complements," or rather "alternating subjective after-colors," as, for instance, in the following example, where alternating subjective perceptions of green and of red have been aroused by

[1] "On the Blending of Colors by the Sole Agency of the Sensorium." By John Gorham, M.R.C.S., Tunbridge; Brain: A Journal of Neurology, vol. iv. p. 467. As early as 1808 Sir David Brewster obtained similar results in an almost identical way. (*Vide*, p. 257 of the first American edition of A Treatise on Optics. By Sir David Brewster, LL.D., F.R.S.L. & E., etc., Philadelphia, 1845.

[2] These experiments might be multiplied almost indefinitely in different ways, with varying though corresponding results. Buffon, Schaeffer, Westfield, Chevreul, Brewster, etc., have all given a great number of interesting modifications of this variety of subjectivism.

sensory and perceptive materials set into activity through the action of either a recognized objective natural green color or a subjective green in producing a red subjective after-color, are most probably dependent upon momentary alternating regains and discharges of sufficient energy material to perceive color energies equal to, first, the primary energy and then its subjective after-color, after having had perceived the subjective after-color. It is a modification of the same old battle though now transferred to the perceptive cells; the changes in the passing results being dependent upon some peculiar condition under which the new variety of weapon is wielded.

So far the first division has been discussed. Endeavors will now be made to explain the causes of the different actions coming under the second head, where the visual apparatus has either an irritant taking birth within itself or a cerebral stimulus to respond to. In the first instance, there cannot be any doubt but that it is possible for the subjective after-colors to be provoked by an irritant affecting any part of the visual apparatus. Suppose the following case: sudden squeezing of the sensory elements of the transmitting parts of the optic nerve, from some momentary blood-pressure increase, with a production of the perception of subjective color. This symptom means that a traumatic stimulus has caused a separation of a definite amount of nerve-energy, which specific quantity is transmitted and perceived as though it had been set into motion by a color-stimulus of external origin. If this traumatic stimulus should be continued for a few moments longer, then suddenly dropped, and the visual apparatus subjected to another act of traumatism, the second subjective visual result would be diminished by as much power as had been extracted by the first act of traumatism, and the answer would be equal to the amount of difference. If the primary irritating force should transmit all of the resident nerve-energy there would not be any perception caused by the second force. These rules hold good for any part of the visual apparatus, no matter whether the exciting stimuli originate in the ocular retina, the conducting nerves, or in the cerebral sheet. Under this category come the answers to the questions suggested by the production of subjective colors when the visual apparatus is not exposed to natural color-stimulus. For easy study there have been two subdivisions made: First, the production of the so-called complements when the organ of sight is in complete darkness; and second, the production of the so-called complements when the organ of sight is directed against a black surface. Practically, these two divisions are the same. The following example illustrates a cause coming under the first subdivision. A man walking in the dark suddenly strikes his eye against a heavy blunt obstacle. He has an immediate subjective perception of red flashes of light. A moment later his organ of sight encounters with much greater force a second

obstacle, and there arises a perception of a subjective green. Here there is a blow upon the outer tunics, followed by a stronger second one, each causing a *contre coup* upon the sensory elements of an equivalent nerve-energy power; the second blow or stimulus having arrived before a formative action for the amount of separated nerve-energy caused by the primary act has taken place.[1] If white light had been the primary subjective color there would not have been any subjective after-color.

Where subjective colors are produced by changes in cerebral structure, or in actions taking their origin within the limits of perceptive material, the same reason for cause and effect as expressed in the paragraph upon subjective color-changes originating from excitants taking their birth within the visual apparatus, must be accepted as truisms, although it should be strictly understood that when, in its studies, the human mentality approaches the domain of the cerebral forces, and demands answers as to the why and the wherefore of the physical changes and the physiological actions occurring within itself, it assumes a position bordering almost upon the search of the infinite. It must be agreed that there are two distinct changes taking place in the conversion of a sensation into a properly recognized perception. First, an action upon the lower mentality by the received sensory result, which has been spread upon the cerebral retina, causing a physical change in the contiguous cerebral material, with a production of the primary form of a perception. Second, a conversion of this automatic perception into a higher form through the action of a conveyed and everchanging quality of perception upon a certain amount of physical material resident near or in the centres of intelligence. These two actions constitute the direct order of the complete evolution of a color-perception as well as the last physiological rule of consummated vision. If it thus be accepted that the evolved perception of a completely sensitized color-energy passes through the same character of stations, and is subject to the same laws, although now of a higher grade of nerve material and cell-action, as it did whilst pursuing its course inwards as a sensation, and that similar acts of separation and re-formation as were attributed to the production of the completed form of color-sensation in the visual apparatus occur in the related perceptive elements of the cerebrum, it must be admitted that momentary alterations and transitory physical changes in these perceptive structures may happen in such a way as not only to produce subjective color-images, but actually to make the *ego* doubt the subjective quality. For instance, suppose the production of a subjective after-color upon a black surface, after the perception of a natural color stimulus. Here the second stimulation upon the perceptive color cells

[1] This example might be multiplied in many ways, and the stimulus made to originate in any part of the visual apparatus, but for proper explanation, this selection is thought to be sufficient.

must be of central origin,[1] because the moment the primary natural force is removed there is absolutely nothing external left to reëxcite the exposed peripheral terminals of the optic nerve. To explain: Suppose that a small square of red color be placed upon a dead-black surface, and a visual apparatus be allowed to fix upon it for several moments by the aid of a good light. Without moving the organ of vision from the point of fixing, have the red square suddenly taken away, and the light decreased to almost a minimum intensity, and there can be made to subjectively appear a green color upon the portion of the dead-black surface previously occupied by the red stimulus. In this experiment a portion of the energy material of the impinged optic nerve filament tip has been separated, evolved, and perceived as red; whilst a remaining nerve-energy material sufficient for the perception of a subjective complement of the transmitted and perceived primary nerve-energy has been left untouched. The acting sensory filament has been lowered to a transmitting power equal to the amount of nerve-energy left in its tip; whilst the internal termination of the filament upon the cerebral retina has been reduced in its power to an amount equal to the difference between its normal equivalent and the quotient of value of the perceived primary nerve-energy. The sudden removal of the natural stimulus, with the substitution of an area that is incapable of throwing out any vibrations of natural color, causes an immediate cessation of separation and transmission of the nerve-energy of the primary stimulus, with an attempt of formative action commencing in the peripheral tip of the abnormalized optic-nerve filament, and passing inwards throughout the whole connected extent of the sensory nerve. Before the restitution of the nerve-force material has reached the central terminus of the tip's filament, there has arisen an excitant in the cerebral cortex, either through will-power or emotion, which excitant has acted upon the acting central terminus of the optic-nerve filament, and caused a separation from the nerve-energy material remaining in the terminus; thus producing a perception of a subjective complement of the primarily perceived color. For obvious reasons, should the experiment have been tried with a square of natural white color, there would not have arisen any true "subjective after-color" at all. If the under larger surface had been gray instead of black, there would have been a visible area of subjective *darkness*, equal in size to the removed white square, because in reality in the above experiment of a white color upon a black surface there is as a result, in addition to the great amount of unused sensory nerve terminals, a small area of exhausted tips, which area is rendered invisible by reason of the non-employment of the surrounding nerve-tips; whilst in the latter experiment upon a gray ground there is a sufficient natural sensitizing material affecting the surrounding optic-nerve fibre tips to cause the area of non-

[1] This excludes internal forces that may arise in the sensory portions of the visual apparatus.

action to be perceptible. (Had the primary natural white stimulus been very strong, there probably might have been a series of passing subjective color changes.)

The same line of reasoning might be used if the primary stimulus had been of internal origin; the only difference being that in this case there would not have been any external stimulus whatever. This might be illustrated by placing the organ of sight in the dark, and causing a second cerebral stimulus to act upon a perceptive color-cell which had been lowered by some previous cerebral act.

All of these observations upon "subjective after-color," whether primarily produced from extraneous or internal stimuli, have dealt with the perceptive cells belonging to the most sensitive regions of either the ocular retina or the cerebral retina.[1] Experiments as to the possibility of the production of subjective after-colors through the peripherally placed cells[2] would be of value; although from the arguments brought forward in this theory it is certain that if sufficient intensities and large enough areas could be given to two complementary natural colors, or that two internal forces equivalent to those from the two natural complements could be aroused, so that their actions would be separately perceived by the eccentrically placed perceptive cell (as we know *is* possible), the subjective after-color of either of the natural colors or of the internal stimuli, could be provoked from the remaining energy of the primarily excited cell.

The other varieties of subjective after-colors are dependent upon modifications of the just described exciting agencies and conditions of physical material. It is for these reasons that no endeavors for their explanation have been given.

Fourth. Color-perception as caused by the action of internal stimuli upon nerve-energies which have not been lowered by any preceding act. Subjective Color. Under this heading come all those visible expressions of actions upon unused perceptive color-cells, through internal force set into activity by internal agencies. It differs from the preceding head in the fact that the color-perceiving cell has not been lowered in its individual forces by any previous act upon its nerve energy material. Here there is *not* a "remaining energy"; the energy is in its entirety, and ready to give subjective visible expression to any color that it has once known objectively. If the material of the nerve energy should be of the finest type, and its visible white of the purest variety, then the more individual color

[1] As this theory presumes a central as well as a peripheral expansion of the visual apparatus analogous to the roots and branches of a tree, it does not seem unjustifiable to speak of the most sensitive region of the cerebral retina, when it is remembered that the individual components of the two retinæ bear equivalent physical and physiological relations with each other.

[2] By "peripherally placed cells" is meant the probable position upon the cerebral cortex of those perceptive color-cells which are the internal representatives of the optic-nerve filaments of the circummacular regions of the ocular retina.

gradations it has under its jurisdiction, and the more subjective colors can be separated from it for perception. This presumes that there is no congenital or hereditary mental power, and that all mental force must have been derived from the external world. (The true reason of "Hereditary Genius" is, that one brain may have a more highly developed material structure, or a stronger physical substance devoted to certain mentalities than another brain, and that the first organ by an equivalent amount of physiological action as the second, may be productive of better work than its less fortunate companion; marking the possessor of the better built machinery as a remarkable "color-seer," or a fine "sound-hearer," etc. If the individual who possesses this better substance should persist in an avocation fitted for the constant use of such structures, he will cause rapid increase of physical material in the parts, and thus through extra powers of receipt and response be brought into eminence.) This is the true foundation of the superiority of one perceptive color-cell material over that of another similarly placed and used cell. This is the reason that there must be different grades of subjective colors dependent upon the strength of variously placed nerve energies and provoked internal stimuli, just as there were differences in objective colors dependent upon the value of the receiving fibre, as well as the amount and character of natural stimuli. Internal stimuli acting upon responsive perceptive material may be assumed in many ways, such as through sudden vascular changes, or by momentary pressures upon sensory tissue. That this is actually so, is fairly presumable from the everyday experiences of the victims of the visual types of either "conscious centric (or subjective) pseudopia," or "unconscious centric (or subjective) pseudopia,"[1] or of "Hallucinations," as Hammond[2] prefers to call them. Yet as it is neither in the province nor in the scope of this paper, to enter more fully into this part of the subject than will be sufficient for explanation of the causes of a few of the prominent varieties of subjective color, all others will be set aside, so as to allow deductions to be drawn from the chosen examples. The varieties will be primarily divided inte two groups—the physiological and the pathological. The former will be treated of here, whilst the latter will be reserved for the third portion of the paper, in order that the various causative stimuli of abnormal nature may be placed in their proper and respective groupings.[3]

[1] These terms first made use of by Dr. Ed. H. Clarke, in an excellent, though unfinished essay upon "Visions: a Study of False Sight (Pseudopia)." Boston, 1878, 8vo., pp. 315.

[2] Divided into two kinds, "recognized" and "delusive." "Diseases of the Nervous System." By Wm. A. Hammond, M.D.

[3] Strictly speaking, hallucinations occurring when the visual apparatus is impressed by natural color, as in ordinary daylight, should be considered as having been caused by actions upon remaining nerve-energies in previously impinged perceptive color-cells.

Physiologically, it does not matter in what internal situation the abnormal stimulus originates. If there should be a momentary attack upon any perceptive color-cell, there would be an immediately perceived action. For instance, the sudden appearance and disappearance of phosphènes from some internal momentary blow upon the region of perceptive color-cells, when the visual apparatus is either in a dark room, or when it is directed against a black surface.[1] Here there is a physiological action of a properly charged color-cell, from an abnormal process of stimulation. The physiological action of the cell is perfect, and the amount of action is dependent upon the force of the internal stimulus.

The same explanation holds good should an experiment be made by which a subjective color should be projected from an unused sensory filament upon a black surface, or into a dark space, during the time that its contiguous filaments are being exposed to strong intensities of natural color for some length of time ; the only difference being that here there is a change in the kind of natural cause, and the character of its invasion. At first sight, it may appear as if it should in reality have been placed under the preceding head "subjective after color," but upon making separation of the reasons for the various manifestations, the proper situation will be found to have been chosen. Here there is a strong internal stimulus from the perceptive cell of the strongly impressed sensory filament acting upon the unused perceptive cell of the unimpinged second sensory filament, giving a definite and equivalent response in the perceptive cell of the second sensory filament. This does not in any way mean that there is an action of a "remaining energy" of the perceptive cell which has been impinged by the internal force, but that the internal stimulus from the primarily lowered perceptive cell is of a complementary type.

Reasoning from these lines of argument, it can be assumed as a certainty that the latter experiment might have been so modified as to cause subjective colors to appear to an unexposed second eye, because even here there is a definite amount, and a definable source of stimulus to attack the working material of the unused organ.[2]

[1] The origin of this force may have been external, as from a blow upon the vault or the cranium.

[2] At this point, "physiological research" is ended. In the concluding paper, which will appear in the April number of this journal, "pathological data in support" and a "*résumé*" will be given.

1507, Locust St.

Article IX.

A Case of Lodgment of a Breech-Pin in the Brain; Removal on the Second Day; Recovery. By G. W. H. Kemper, M.D., of Muncie, Indiana.

On the 19th day of April, 1884, Emerson McC., a robust farmer boy, aged 18 years, received a compound fracture of the frontal bone, immediately above the right frontal sinus, by a bursting gun. About noon, as ascertained from persons who heard the report of the gun, while the weapon was in position before his face, he fired at a squirrel. Four hours later he made his way, unaided, to his father's home. An investigation revealed the facts that the accident had occurred one-half a mile from the home, the gun had been broken into numerous pieces, and he had lain on the ground for a considerable length of time in an insensible condition. The hemorrhage had been moderate in quantity, and about half a teaspoonful of brain substance was found upon the leaves.

Dr. D. O. Munsey, of New Corner, the family physician, was summoned, and arrived about six o'clock. He found the patient suffering but little pain, and his mind was clear. Cold water dressings were applied—a critical examination of the wound being postponed for a consultation.

At 9 A.M. of the 20th—about twenty-one hours after the receipt of the injury—I saw the patient. The temperature was $104\frac{3}{4}°$; pulse 64. He felt but slight pain, and the mental faculties were unclouded. He had slept well during the night. The tissues around the right eye were considerably swollen, and blackened with powder stains. A partially curved wound, about one and a half inches long, was located vertically above the right eyebrow. Raising the valve-like flap of skin, I found quite an aperture through the two plates of the frontal bone. Passing my finger through this and into the brain to search for any pieces of bone that might be detached, at a distance of half an inch beyond the internal plate, I felt a serrated object, and, guided by my finger, I introduced a dressing forceps, and seized and withdrew it—the breech-pin of a gun.

I presume the characteristic shape of the wound of the skin and soft tissues was made by the iron striking with its long diameter. After entering the cranial cavity the base of the pin advanced, and left the small end towards the point of entrance, and this was the point I first touched. Some five or six small pieces of detached bone were removed at this time, and two or three more, with a piece of his felt hat, worn at the time of the accident, appeared at the opening of the wound, several days later, and were removed by Dr. Munsey.

During all the time of my manipulations the patient made but slight complaint of pain—having refused to inhale an anæsthetic. The shape and natural size of the iron is shown in the accompanying cut (Fig. 1). The iron weighed 617 grains; length, $1\frac{1}{2}$ inches.